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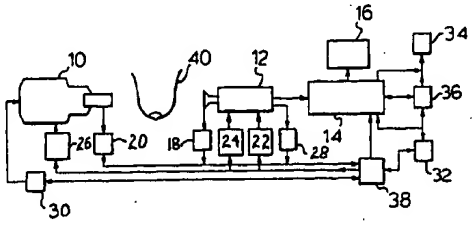
(54) Title: METHOD AND APPARATUS FOR EXAMINING TISSUE BY TRANSILLUMINATION USING NEAR INFRARED LIGHT



(57) Abstract

A method of automatically generating a standardized image of an illuminated object uses a transillumination apparatus comprising a light probe (10) having a light source (62) emitting a scattered light beam, a CCD camera (12) having a lens aperture for controlling the amount of light received by the CCD camera (12) and an amplifier for amplifying an output signal proportional to the amount of light received by the CCD camera, a computer processing system (38) and a monitor. The method comprises the steps of illuminating an object with the scattered light beam; collecting the light beam with a CCD camera (12) after the light beam has passed throught the object; transforming the collected light into an image having a mean grey scale and displaying the image on a monitor; comparing grey scale of the image with a pre-assigned upper threshold and lower threshold and generating a plurality of control signals to automatically regulate the opening of the lens aperture, the gain of the CCD camera and the brightness of the light source until the mean grey scale of the image lies within the preassigned upper threshold and lower threshold.

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METHOD AND APPARATUS FOR EXAMINING TISSUE BY TRANSILLUMINATION USING NEAR INFRARED LIGHT

Field of Invention

This invention relates to an apparatus for examining breast tissue for diagnostic purposes by trans-illumination using near infrared wavelengths of light.

Background of the Invention

Transillumination photography using infrared light has been widely employed for medical diagnosis of changes in the breast. This type of technology utilizes two different bandwidths of light, a wide spectral band (400 - 1500 nm), and a narrow spectral band (700 - 900 nm) to transilluminate the breast tissue (see for example Cartwright CH. Infrared transmission of skin. J Opt Soc Am 1930:20:81-4; Hardy JD. Hammel HT. Murgatroyd D. Special transmittance and reflectance of excised human skin. J Appl Physiol 1956:9:257-64; Morton R. Miller SS. Infrared transillumination using photography and television (videodiscopy). J. Audiov Media Med 1981:4:86-90; R. Lafreniere, F. Ashkar, A. Ketcham. Infrared light scanning of the breast. The American Surgeon, March 1986, Vol.52.). The transmitted light from the breast tissue is captured by a camera and the signal is fed into a computer processor which transfers the image onto a video monitor. The advantages of this technology are that it uses safe infrared light, real-time imaging and it has an easy operation during examinations.

Since the characteristics of absorption, reflection, and transmission of light in the body are different for different wavelengths of light and the overall light transmission is low, a uniquely designed light source and camera are required to produce effective images for diagnosis.

The detection system, such as those disclosed in Chinese Patent Application, CN-90101352 and United States Patent no. 4,898,172, use infrared light for detection of pathological changes in breast tissue. The system consists of: a light source probe for illuminating the breast; a video camera to receive the image formed from the scattered light transilluminated through the tissues; a computer graphic processing system for processing images received; and a video monitor for displaying images of the breast being examined.

The probe is constructed of a heat insulating case with the light source installed at the center. The light source is a tungsten filament lamp that has the ability to produce visible infrared light of wide bandwidth or narrow bandwidth. Encased in the tapered end of the probe is a transparent rod which functions as a wave guide for the light as well as a heat insulator. The rear of the probe is also provided with a cooling fan.

During the examination, the technician or doctor places the tip of the probe tightly against the breast. Light passes through the transparent rod and is emitted from an output source. As light is transmitted through the breast, a portion of the beam is absorbed by the breast tissue, while the remaining portion is transmitted through the breast tissue and captured by a camera. The signal from the camera is then fed into an image processing computer where it is displayed on the video monitor.

In the past, the transmitted light had to be maintained at a high level of intensity to compensate for the low sensitivity of the camera. To offset this limitation, the intensity of the light source was increased, and the output surface of the glass rod was refined and polished, to produce a more concentrated light beam at its center. Light emitted from the probe is generally collimated light having a diameter of the light beam almost the same as the diameter of the output surface of the probe, normally about 2-3 cm in length. Hence, only a small area of the breast was illuminated. Furthermore, the concentration of the light intensity at the center of the light beam caused uneven illumination of the breast tissue. Consequently, the resolution and sharpness of the captured image, along with the accuracy of the detection, were reduced.

Further, if there is a lesion near the root of the breast being examined and the examiner does not move the probe carefully, the illuminated area will not discover the lesion, resulting in an inaccurate detection and diagnosis.

Although state-of-the-art CCD cameras have improved sensitivity thereby reducing the intensity requirement of the light source, a higher demand is placed

on the resolution and sharpness of the video image.

The Chinese Patent CN-90101352 discloses an imaging method and system for the examination of breast tissue. This device used a visible wide spectrum scattered near-infrared light to illuminate the breast tissue being examined. A CCD camera, set up at a certain angle with the emission surface of the scattered light captured the light transmitted through the breast tissue. The signals obtained are processed by the computer and the differences in grey scales between the images of the abnormal and normal positions are shown on the monitor. The diameter, the projected area and the volume of the pathologically changed position are estimated. This may provide the physician with information to make a quantitative analysis of the pathological change.

European Patent EP-0108617 discloses a tele-diaphanoimaging system having a light source head with wavelengths from 300 nm to 2000 nm, a light detector for detecting the light transmitted through the transilluminated tissue being examined, a visual display unit and a recording device to record the images.

International Patent publication WO-88/0827 discloses a system for examining breast tissues which was composed of an infrared light source head, a TV camera for receiving the light transmitted through the transilluminated tissues, a computer imaging processor, an ultrasound generator and an ultrasound detector.

Due to a lack of distinctiveness in the images, the different ages of patients being examined and the different densities of their breast tissue, the operator is required to adjust the brightness of the emitted light from the light source head, the aperture of the CCD camera lens and the CCD camera gain for each examination in order to obtain a clear and accurate image suitable for detection. The time-consuming process of calibrating results in low efficiency in detection and an unpleasant procedure for the patient.

Further, not every operator can obtain the best quality of images. This ability will be dependent on the level of training and the operator's medical background. These obstacles have limited the wide use of such detection devices.

It takes time for the breast illness to develop in a patient, as well as in the treatment of the illness. Generally, such a patient will undertake several detections to make certain that the illness still exists or has been cured. The doctor compares the images obtained from each detection. The problem with such a comparison is that the subsequent examinations may be undertaken with different imaging parameters. Thus, an inaccurate comparison is made.

Further, some of the prior art systems cannot regenerate the imaging parameters of the stored images of the previous detection. This deficiency affects the accuracy and efficiency of the patient's re-examination.

Summary of the invention

The disadvantages of the prior art may be overcome by providing a method of uniform imaging, by means of automatic regulation of the brightness of the light source, the focal length and the aperture of the CCD camera lens and the gain of the CCD devices.

It is desirable to provide a light source probe that will uniformly transilluminate a relatively large area of the breast being examined.

It is desirable to provide a system which is "an intelligent system", which is able to judge the quality of the images obtained and is able to regulate various parameters involved during imaging.

According to one aspect of the invention, the output surface of the rod at the tip of the probe is polished to a ground glass texture forming a plurality of light scattering areas causing the emitting collimated light to be dispersed. The scattering increases the emitting solid angle of the beam and creates a more uniform illumination, without increasing the intensity.

According to another aspect of this invention, the output surface of the rod is ground to form rows of teeth in a net-like or criss-cross configuration to increase the scattering of the collimated light. The improved uniformity in the distribution of light intensity and a wider emitting solid angle improves the uniform illumination.

According to another aspect of the present invention, there is provided an

apparatus for examining breast tissues and producing a standardized image of a breast. The apparatus comprises:

a light probe to transilluminate breast tissues being examined with a light, the probe comprising a housing having an illuminating end for abutting against a breast for illuminating breast tissue thereof, a light source mounted within the housing for generating a light beam, and a light transmitting rod mounted at the illuminating end of the housing for receiving the light beam and collimating the light beam as it passes therethrough and having a textured output surface for scattering the light beam as the light beam exits the rod, a cooling fan mounted within the probe for positively circulating cooling air through the housing;

a CCD camera to collect light transilluminated through the breast tissues;

a computer processing system for transforming the collected light into an image, the computer processing system comprising a graphic storage, a network and a printer;

a monitor connected to the computer graphical processing system for displaying the image having a mean grey scale;

a first sensor adapted for detecting the brightness of light emitted from the light probe;

a second sensor adapted for gauging the gain of the CCD camera;

a third sensor adapted for detecting the mean grey scale of the image;

a light regulating system for regulating the brightness of the light probe in response to the computer data processing system;

a lens regulating system for regulating the lens aperture of the CCD camera in response to the computer data processing system;

a CCD gain regulating system for regulating the gain of the CCD camera in response to the computer data processing system;

a fifth sensor for measuring the temperature of the probe;

a sixth sensor for measuring the focal length of the CCD camera lens;

a seventh sensor for measuring the brightness of the surrounding light;

an eighth sensor for measuring the focal length of the CCD camera lens;

a control keyboard for controlling operations during the course of imaging, wherein the control keyboard is connected to the computer data processing system and to the light source probe respectively;

wherein the computer data processing system monitors the sensors and generates a plurality of control signals responsive to the sensors for regulating the image to a standardized image.

According to another aspect of the invention, there is provided a an electronic storage for recording the image of the breast being examined, together with the image parameters for generating the image whereby the image may be regenerated for comparison with a later generated image.

According to another aspect of the invention, there is provided a method of automatically generating a standardized image of an illuminated object using a transillumination apparatus comprising a light probe having a light source emitting a scattered light beam, a CCD camera having a lens aperture for controlling the amount of light received by the CCD camera and an amplifier for amplifying an output signal proportional to the amount of light received by the CCD camera, a computer processing system and a monitor. The method comprises the following steps:

illuminating an object with the scattered light beam;

collecting the light beam with a CCD camera after the light beam has passed through the object;

transforming the collected light into an image having a mean grey scale and displaying the image on a monitor;

measuring the brightness of the light source and generating a first signal proportional thereto;

measuring the opening of the lens aperture of the CCD camera and generating a second signal proportional thereto;

measuring the gain of the CCD camera and generating a third signal proportional thereto;

measuring the mean grey scale of the image and generating a fourth signal

proportional thereto;

transmitting the signals to the computer data processing system for reiteratively comparing the signals with a pre-assigned values and generating a plurality of control signals to automatically regulate the opening of the lens aperture, the gain of the CCD camera and the brightness of the light source until the mean grey scale of the image lies within a pre-assigned upper threshold and lower threshold,

wherein if the fourth signal is greater than the pre-assigned upper threshold, then the gain of the CCD camera is incrementally decreased until the fourth signal is less than the upper threshold value or until the third signal is at a minimum;

if the third signal is at a minimum and the fourth signal is still greater than the upper threshold, then the lens aperture of the CCD camera is incrementally decreased until the fourth signal is less than the upper threshold or until the third signal is at a minimum;

if the third signal is at the minimum and the fourth signal is still greater than the upper threshold, then the brightness of the light source is incrementally decreased until the fourth signal is less than the upper threshold;

if the fourth signal is less than the pre-assigned lower threshold, then the gain of the CCD camera is incrementally increased until the fourth signal is greater than the upper threshold or the third signal is at a maximum;

if the third signal is at its maximum and the fourth is still lower than the lower threshold, then the lens aperture of the CCD camera is incrementally increased until the fourth signal is greater than the lower threshold or the second signal is at a maximum;

if the second signal is at its maximum and the fourth signal is still lower than the lower threshold, then the brightness of the light source is incrementally increased until the fourth signal is higher than the lower threshold.

According to another aspect of the invention, there is provided a method of recording the image of the breast being examined, together with the image parameters for generating the image and regenerating the image for

comparison with a later generated image.

According to another aspect of the invention the method includes the steps of retrieving the recorded first second and third signals, increasing or decreasing the gain of the CCD camera until the third signal equals the recorded third signal, increasing or decreasing the lens aperture of the CCD camera until the second signal equals the recorded second signal, increasing or decreasing the brightness of the light source until the first signal equals the recorded first signal.

Description of the Drawings

The properties and the advantages of the invention will be presented and explained in more details with the following diagrams:

Figure 1 is a schematic diagram of the present invention;

Figure 2 is a schematic diagram of the sensor array of the invention of Figure 1;

Figure 3 is aside sectional view of the light probe of the invention of Figure 1;

Figure 4 is an end view of the tip of the light probe of the invention of Figure 1;

Figure 5 is an end view of a second embodiment of the tip of the light probe of the invention of Figure 1;

Figure 6 is a sectional view of the tip of the light probe along the lines A-A of Figure 5;

Figure 7 is a plan view of the keyboard of the light probe of the invention of Figure 1;

Figure 8 is a side elevational view of the light transmitting rod of the light probe of the invention of Figure 1;

Figures 9-13 are perspective view of the light transmitting rod of the light probe of the present invention in successive stages of manufacture;

Figure 14 is a flow diagram of the process to standardized an image generated by the invention of Figure 1;

Figure 15 is a flow diagram of the process to regenerate the image and

imaging parameters of the invention of Figure 1;

Figure 16 is a schematic diagram of the light probe and CCD camera of the invention of Figure 1 examining a human breast;

Figure 17 is a schematic diagram of an experimental set-up for comparing the spatial distribution and contour lines of the invention of Figure 1 against prior art device;

Figure 18 is a graph of the spatial intensity distribution of the emitted light at position "A" produced by the prior art technique;

Figure 19 is a graph of the spatial distribution contour lines of the emitted light intensity corresponding to Figure 18;

Figure 20 is a graph of the spatial intensity distribution of the emitted light at position "B" in Figure 17 produced by the prior art technique;

Figure 21 is a graph of the spatial distribution contour lines of the emitted light at position "B" in Figure 17 corresponding to Figure 20;

Figure 22 is a graph of the spatial intensity distribution and contour lines of the emitted light at position "A" in Figure 17 produced by the present invention having a rod having a ground glass texture;

Figure 23 is a graph of the spatial distribution and contour lines of the emitted light corresponding to Figure 22;

Figure 24 is a graph of the spatial intensity distribution and contour lines of the emitted light at position "B" in Figure 17 produced by a rod having a textured surface;

Figure 25 is a graph of the spatial distribution and contour lines of the emitted light corresponding to Figure 24.

Description of the Invention

Figure 1 a schematic diagram of the method and system of the present invention. As shown, the breast 40 is examined by illuminating the breast 40 with the light source probe 10. A CCD camera 12 is set up on the other side of the breast 40 to capture the light transilluminated through the breast tissue. The graphic signals from the camera 12 are transmitted into the computer graphic

processing system 14 and then displayed on the monitor 16. Brightness sensor 20 is located in the light conductor at the front of the light source probe 10 and detects the brightness of the light source. Eigenvalue sensor 18 of the lens aperture is located in the CCD camera 12 to gauge the size of the lens aperture of the CCD camera 12. Eigenvalue sensor 28 is connected with the CCD camera 12 and gauges the gain value of the CCD camera 12.

The regulating systems are comprised of regulating system 22 for controlling the gain of the CCD device, regulating system 26 for controlling the brightness of the light source and regulating system 24 for controlling the focal length of the CCD camera lens.

The data processing system 38 further comprises a control keyboard 30 which is attached to the case of the light source probe 10. Using different keys on the keyboard 30, the operator may make selections to regulate parameters automatically or manually. The brightness of the light source 10 can be controlled, the parameters can be placed in a "lock-in" mode or the images may be kept "in freeze mode". The term "lock in" refers to maintaining the value of every parameter on a set value. Generally it is used in the course of consecutive examinations to prevent insignificant changes to certain parameters. The term "in freeze mode" refers to the preservation of the image displayed on the monitor.

The system also includes a printer 34 for printing detected images and information and a computer service system 36 for communicating between the physicians and the nurses, and for providing case history consulting.

The present invention further comprises a temperature sensor 42 for detecting the temperature of the light source, a sensor 44 for surveying the focal length of the CCD camera lens and a brightness sensor 46 for detecting the surrounding light.

Figure 2 illustrates a flow chart of the signals and data transmitted during

an application of the present invention. There are seven sensors involved: an eigenvalue gain sensor 28 for the CCD devices; a mean grey scale sensor 48 of the images; a brightness sensor 20 for the light source; an eigenvalue sensor 18 for the lens aperture of the CCD camera, a focal length sensor 44 for the CCD lens, a temperature sensor 42 for the light source probe 10, and a brightness sensor 46 for the surrounding light.

Each sensor is connected to an A/D converter 50 which converts analog signals into digital signals and which are then transmitted to the computer data processing system 38 for comparison and processing. On the basis of the results, control signals are emitted and transmitted to the corresponding regulating systems for automatic regulation of relevant parameters. Determined parameters may be stored in information storage 32. Of these parameters, the gain eigenvalue of the CCD device, the mean grey scale of the image, brightness of light source, and the eigenvalue of the lens aperture of the CCD camera are essential to maintain a standard image.

The computer data processing system 38 is connected to the brightness sensor 20, the eigenvalue sensor 18 of the lens aperture, the gain sensor 28 of the CCD devices, the mean grey scale sensor 48 of the image, and the computer data processing system 38 receives various parametric signals emitted from the aforementioned devices and compares each input parameter value with a corresponding pre-assigned value. On the basis of the comparison, the computer data processing system 38 sends control signals to the gain regulating system 22 of the CCD camera to regulate the gain of the CCD camera, to the regulating system 24 of the lens aperture of the CCD camera 12 to regulate the aperture of the CCD lens and to the brightness regulating system 26 to regulate the brightness of light source 62. The above-mentioned systems regulate appropriate parameters, until all the imaging parameters and the imaging parameters of acquired images are standardized and uniform.

Figure 3 illustrates the structure of the light source probe 10 which is comprised mainly of an outer case 50 made of an opaque and heat insulating

aluminum with a preferred thickness of 0.3 ~ 0.5 mm. The light conductor is a rod 52 preferably having a cross-sectional shape as illustrated in Figure 4. It is highly transparent and insulates heat well. There is a layer of aluminum foil 54 on the lateral side that permits total internal reflection and emission only at the output surface 56. Due to the reflection of the concave mirror 58, light emitted from the light source becomes a near collimated light. The concave mirror 58 absorbs visible light and reflects the wavelength of light in the range of 700 - 900 nm. The light from the light source enters the rod 52 from its rear surface 60 and is emitted from its output surface 56 in the front of probe. The rear and output surfaces of the rod 52 forms a light passage in the probe.

The light probe 10 includes a light source 62, a concave mirror 58, an intensity control unit 64, a cooling fan 66 and a power cord 68. The shape and size of the probe 10 is designed to be hand-held. In order for the probe 10 to be used effectively, the output surface 56 and the rear surface 60 are oriented at a predetermined angle relative to the direction of the light beam. The light source control unit 64 allows for adjustment and control of light intensity. This control unit 64 is connected to the control panel 30 by a wire 72. Control panel 30 is mounted on the case 50 of the probe 10.

The front part of the probe has two cases. A hollow annular space is defined between the outer case 50 and the inner case 80. When the cooling fan 66 is on, cooling air is positively circulated through the openings 82 through the annular space between the outer case 50 and the inner case 80, into the openings 84 into inner case 80. The air is then heated by the light source and expelled through the exhaust opening 86. Since the light source 62 generates a large amount of heat, cooling fan 66 prevents injury to the operator or the patient.

As illustrated in Figure 7, the control buttons include a manual/automatic switching button 74 for switching between modes of operation, button 76 for increasing light intensity and button 78 for decreasing light intensity. Both buttons 76 and 78 are variable control type buttons. The purpose of adjusting the light intensity is to control the sharpness of the image.

Control panel 30 may optionally have key 122 for freezing the images, and to hold and store the images. Pressing key 122 will freeze the images shown on the display and store them in the graphic memory 32. In addition, there is a graphical parameter regeneration key 123 and a parameter "lock-in" key 124. The graphical parameter regeneration key 123 is used to regenerate imaging parameters of the images of selected past cases. The imaging parameters refer to the above mentioned brightness of the light source lens aperture eigenvalue of the CCD camera and gain eigenvalue of CCD device. The lens focal length eigenvalue, temperature of the probe, and surrounding light brightness are only used for reference during an examination. In regenerating an image, these parameters do not necessarily have to be regenerated. Imaging parameter "lock-in" key 124 is used to "lock-in" selected imaging parameters during an examination to prevent unintentional variations in these values.

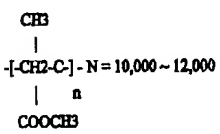
The output surface 56 of the rod 52 is polished into a *ground glass texture* using an appropriate type of grind paste. The result is the formation of many tiny teeth on the surface which scatter the nearly collimated light beam from the source. The output surface 56 increases the emitting solid angle of the light beam and the uniform distribution of light intensity producing a larger illuminated area in the breast.

Referring to Figure 5, the output surface 56 of the rod 52 may be polished to a *lattice* feature of at least two rows of regular parallel convex crisscrosses. If viewed from above the surface, many small convexes appear as a straight line. If the output surface 56 consisted of two rows of parallel convex crisscrosses, there would be a seven-sided trapezoidal in each convex. The seven distinct orientations of these sides produce a wider scattering of the light beam, increasing the emitted solid angle and a uniform distribution of light intensity to a greater magnitude.

Meticulous cutting and polishing of each convex and its seven sides creates an output surface of higher transparency and scattering capability. Since the overall amount of each side is the same for all seven directions, light emitted from

this surface have a wider and more uniform area of illumination.

In the preferred embodiment, the rod 52 is made of a polyethylene methacrylate, standard: HG2 - 343 - 76:



Polyethylene methacrylate has a transparency of between 90-92%. Preferably, the area of output surface of rod 52 is between: 10.8 - 12.8 cm^2.

The rod is manufactured by a machine shaping process, as shown in Figures 9 to 13. The raw rod 88 is cut to length roughly defining the angles of surfaces 56 and 60. One end is then machined to reduce the diameter thereof. The machined rod is then polished. Surface 56 is serrated and then contoured for the finishing surface.

The control of the apparatus is generally illustrated in the flow chart of Figure 14. The reference boxes have the following definitions:

101:	DOES FOCAL LENGTH FIT?	602:	OPTIMAL MEAN GREY SCALE
102:	REGULATE FOCAL LENGTH OF LENS	603:	MANUAL FINE REGULATE OF BRIGHTNESS OF LIGHT SOURCE
201:	MEAN GREY SCALE > UPPER THRESHOLD VALUE?	604:	IMAGES IN FREEZE MODE
301:	MINIMUM CCD GAIN	701:	MAXIMUM CCD GAIN
302:	DECREASE THE CCD GAIN	702:	INCREASE CCD GAIN
401:	MINIMUM APERTURE OF LENS	801:	MAXIMUM APERTURE OF LENS
402:	DECREASE THE APERTURE OF LENS	802:	INCREASE APERTURE OF LENS
501:	DECREASE THE BRIGHTNESS OF LIGHT SOURCE	901:	INCREASE THE BRIGHTNESS OF LIGHT SOURCE

In step 101, the operator, based on the distinctiveness of the image, determines whether the focal length of the CCD camera lens is appropriate or

not; if not, the operator will proceed to step 102, which is to regulate the focal length of the lens, then go back to step 101. Once the focal length of lens is acceptable the operator may proceed to step 201. Since the lens used in the CCD camera is generally relatively short, its depth of field is sufficient enough that when coarse adjustment is made during operation, fine regulation is usually not necessary. Thus, step 101 and 102 may be completed rapidly on subsequent examinations.

At step 201, the actual mean grey scale of the images obtained is compared with the pre-assigned value of the mean grey scale's upper threshold. If the comparison shows the mean grey scale of the images is not higher than the upper threshold value, go to step 601, otherwise, go to step 301.

At step 301, the value of the CCD device gain, obtained from the gain eigenvalue sensor for the CCD device, is compared with the minimum value in its work area. The work area of the above mentioned CCD device is pre-assigned. Usually the best region in the normal work area of CCD device is selected for the comparison value in step 301. If the actual CCD gain value is already at its minimum, then go to step 401. If the actual CCD gain is not at its minimum, then go to step 302. At step 302, the computer data processing system 38 sends out a signal to the CCD gain regulating system 22 which automatically decreases the CCD gain by an incremental amount.

In step 302 and step 702, the range of regulation for the CCD gain is pre-assigned and can be adjustable. This range is determined by the changes of the mean grey scale of the image. For example, the selected optimal work area in step 301 may be divided into ten intervals. In step 302 and in step 702, every time only one interval range (that is, one tenth of the original range) is taken for the regulation of CCD gain.

After step 302, return to step 201. If once again the obtained mean grey scale of the images is not greater than the pre-assigned upper threshold value, then go to step 601. If mean grey scale of the image is still higher than the pre-assigned upper threshold value, then repeat step 301, 302 and step 201, until the

obtained mean grey scale value of the image is no longer higher than the assigned value of upper threshold. Once the mean grey scale value is acceptable, the system then goes to step 601.

In step 401, the lens aperture number detected by the lens aperture eigenvalue sensor 18, which is set up on the CCD camera, is compared with the minimum possible aperture. If the actual lens aperture number is already minimum, go to step 501. If the actual lens aperture number is larger than the minimum aperture number, then go to step 402.

At step 402, the computer data processing system 38 sends out control signals to the regulating system of lens aperture 24, to decrease the aperture by one grade, then return to step 201. These steps are repeated until the obtained mean grey scale value is no longer higher than the assigned upper threshold value.

In step 501, when regulating system 26 has received the control signals transmitted from the computer data processing system 38, the brightness of light source will incrementally decrease until the obtained mean grey scale value of the image is less than the assigned upper threshold value.

At step 601, the detected mean grey scale of the image is compared with the pre-assigned mean grey scale's lower threshold value. If the comparison shows that the mean grey scale is higher than the pre-assigned lower threshold value, then go to step 602. If the mean grey scale value is lower than the pre-assigned lower threshold value, then go to step 701.

At step 701, the computer data processing system 38 compares the gain eigenvalue of the CCD device surveyed at that time with the maximum value of the optimal work area of CCD device. If the CCD gain at that time is already at its maximum, then go to step 801, otherwise, go to step 702. Regulate the gain value of the CCD device in the same way as stated in the foregoing step 302, but in the opposite direction, that is, increase the CCD gain step by step. Then go to step 601 again. Repeat this until the mean grey scale value of the images shown on the display is higher than the pre-assigned lower threshold value, then

go to step 602. If the actual CCD gain has already reached its maximum, the obtained mean grey scale of the image still is less than the assigned lower threshold value, then go to step 801.

In step 801, if the present lens aperture is the maximum, go to step 901. If not, go to step 802 to increase the aperture by one grade, then return again to step 601. Repeat this cycle until the obtained mean grey scale of the images is higher than the assigned lower threshold value, then go to step 602, unless the aperture has already reached the maximum and the mean grey scale obtained still is less than the assigned lower threshold value, then go to step 901.

At step 901, the brightness of the light source is increased step by step until the mean grey scale value of the image obtained is not less than the assigned lower threshold value, then go to step 602. When step 602 is reached, the mean grey scale of the image will be in the optimal area, or at the "Expert value" level. At that moment, if the images on the display can be preserved if so desired by proceeding to step 604. With the image "freeze mode" device, the image is kept in "freeze" state for later reference or printing. Manual fine regulation of the light source brightness is available to the operator. If the operator is not satisfied with the images obtained, it is possible to change the mode of regulation of the parameters from automatic to manual by switching the automatic/manual key 74 attached on the case of the light source probe. When the key is in the manual mode, the brightness of the light source can be fine adjusted with the light source brightness knob, until satisfactory results are obtained.

Pressing key 122 will freeze the images shown on the display and store them in the graphic memory 32. In addition, there is a graphical parameter regeneration key 123 and a parameter "lock-in" key 124. The graphical parameter regeneration key 123 is used to regenerate imaging parameters of the images of selected past cases. The imaging parameters include brightness of the light source, lens aperture eigenvalue of the CCD camera and gain eigenvalue of CCD device. Lens focal length eigenvalue, temperature of the probe, and surrounding light brightness, are only used for reference during an examination. Imaging

parameter "lock-in" key 124 is used to "lock-in" selected imaging parameters during an examination to prevent unintentional variations in these values.

In the preferred embodiment, the image is recorded on a video cassette recorder during the entire scanning process. The recorded image provides a continuous image of the breast which can improve the comparison with the regenerated of locked-in image.

Since the present invention adopts the above described method of regeneration of imaging parameters, the quality of the images obtained by the non-ionizing infrared light transillumination detection system no longer depend on the skill level of the operator, but instead is maintained on a constant standard level throughout. Moreover, this method is automatically regulated by the above-mentioned computer processor, thus, decreasing the time for examination and increasing the reliability and efficiency of the examination procedure.

Figure 15 is a flow-chart of an optimal application of the regeneration of imaging parameters of the present invention. The reference boxes have the following definitions:

110:	GO OUT	511:	BRIGHTNESS OF LIGHT SOURCE RECORDED VALUE
111:	RECALL RECORDED PARAMETERS	512:	LIGHT SOURCE BRIGHTNESS REGULATION
211:	REGENERATE RECORDED PARAMETERS	611:	PARAMETERS LOCK IN
311:	CCD GAIN RECORDED VALUE	612:	LIGHT SOURCE BRIGHTNESS FINE REGULATION (MANUALLY)
312:	CCD GAIN REGULATION		
411:	LENS APERTURE RECORDED VALUE	711:	IMAGE LOCK IN
412:	LENS APERTURE REGULATION		

When a patient is being a re-examined, the operator recalls the patient's medical record from the information storage 32. The images detected in the previous examination and the stored values of the imaging parameters are displayed at the same time on the monitor.

At step 111, the operator should decide if the stored parameters are to be

used. If not, then the program returns to the regular program. Otherwise, the stored parameters are read into the computer data processing system 38, then enter step 211. If the operator does not want to use the regeneration imaging parameters, the program returns to the regular program again. Otherwise the program enters step 311.

At step 311, the computer data processing system 38 compares the eigenvalue of the CCD gain from sensor 28 with the recorded eigenvalue of the CCD gain. If the value does not equal each other, the program enters step 312.

At step 312, a control signal is sent by the computer data processing system 38 to the CCD gain controller 22, which increases or decreases the CCD gain, step by step until the actual CCD gain is equal to the recorded CCD gain. Then the program enters to step 411.

At step 411, the computer data processing system 38 compares the eigenvalue of the lens aperture from sensor 18 with the recorded value of the lens aperture. If the value does not equal each other, the program enters step 412.

At step 412, a control signal is sent by the computer data processing system 38, to the lens aperture controller 24 which increases or decreases the value of the lens aperture step by step until the actual lens aperture is equal to the recorded value. Then, the program enters step 511.

At step 511, the computer data processing system 38 compares the brightness of the light source from the sensor with the recorded brightness, if the value does not equal each other, the program enters step 512.

At step 512, a control signal is sent by the computer data processing system 38 to the brightness controller which increases or decreases the brightness step by step until the actual brightness is equal to the recorded brightness. Then the program enters step 611.

At step 611, the adjusted imaging parameters are "locked-in". Now the operator may adjust the position of the light source probe and observe the images on the monitor. When a suspicious area is found, the operator can either "lock in" the images or adjust manually the fine adjusting key to achieve a clearer

image.

The distinct advantages of the present invention are evidenced by the results of the experiments conducted below by the inventor. First, an object is located in-between the light conducting unit and the camera, which adducts the intensity of the light source to obtain an image. The result of the comparison experiment shows that the existing technique and the illuminating solid angle of the light source probe having a polished front and rear surface light conducting unit is in line with the light passage calibre of the light conducting unit.

Referring to Figure 16, when the light source probe 10 is used to illuminate breast 40, the illumination will cover most of the breast, due to a more uniform and wider area of light intensity. The image produced by the camera 12 is the reflection of tissue of the breast. Thus, any lesion 90 in the root of the breast may be easily detected.

Figure 17 is an experimental set-up for comparing the spatial distribution and contour lines of the emitted light intensity. The intensity of the light source is adjusted to a non-saturation condition. A camera 12 is placed facing the light source at position "A" directly in line with the light source 62, or the camera 12 is placed at position "B", offset from the collimated light, which is facing the output surface 56. Figures 18 to 25 show respectively the spatial distribution and contour lines of the emitted light intensity.

Figure 18 is a graph of the spatial intensity distribution of the emitted light at position "A" produced by the glass rod of the existing technique, which is polished at the front and rear surfaces. Figure 19 is a corresponding graph of the spatial distribution contour lines of the emitted light intensity.

Figure 20 is a graph of the spatial intensity distribution of the emitted light at position "B" in Figure 17 produced by the glass rod of the prior art technique, which is polished at the front and rear surfaces. Figure 21 is a graph of the spatial distribution contour lines of the emitted light at position "B" in Figure 17 produced by the glass rod of the prior art technique.

Figures 18 to 21 shows that the light conductor does not change the energy

spatial distribution of the light emitted from the light source.

Figure 22 is a graph of the spatial intensity distribution and contour lines of the emitted light at position "A" in Figure 17 produced by the rod of the present invention having an output surface 56 which is polished to a ground glass texture. Figure 23 is a graph of the spatial distribution and contour lines of the emitted light at position "A" in Figure 17 produced by the rod of the present invention.

Figure 24 is a graph of the spatial intensity distribution and contour lines of the emitted light at position "B" in Figure 17 produced by the rod of the invention, which is polished to a ground glass texture. Figure 25 is a graph of the spatial distribution and contour lines of the emitted light at position "B" in Figure 17 produced by the rod of the present invention, which is polished to a ground glass texture.

The improvement over the prior art techniques of the present invention are evidenced in Figures 22 through 25. These include the texture of the output surface of the light source probe, which creates a scattered design and the change of spatial distribution of light energy emitted from light source, which increases the solid angle of emitted light and improves uniformity.

It is apparent that any technician in this field of technology will understand that the application of the present invention includes more than the examples presented. It also encompasses many other improvements that may be achieved from this invention.

Moreover, the application of the present invention is not restricted to infrared light breast detection apparatuses, but may be applied to any detectors which use other bandwidth light to illuminate the breast tissue.

I Claim:

1. A method of automatically generating a standardized image of an illuminated object using a transillumination apparatus comprising a light probe (10) having a light source (62) emitting a scattered light beam, a CCD camera (12) having a lens aperture for controlling the amount of light received by the CCD camera (12) and an amplifier for amplifying an output signal proportional to the amount of light received by the CCD camera, a computer processing system (38) and a monitor, the method comprising the following steps:

illuminating an object with the scattered light beam;

collecting said light beam with a CCD camera (12) after said light beam has passed through said object;

transforming the collected light into an image having a mean grey scale and displaying the image on a monitor;

measuring the brightness of the light source and generating a first signal proportional thereto;

measuring the opening of the lens aperture of the CCD camera and generating a second signal proportional thereto;

measuring the gain of the CCD camera and generating a third signal proportional thereto;

measuring the mean grey scale of the image and generating a fourth signal proportional thereto;

transmitting said signals to the computer data processing system (38) for reiteratively comparing said signals with a pre-assigned values and generating a plurality of control signals to automatically regulate the opening of the lens aperture, the gain of the CCD camera and the brightness of the light source until the mean grey scale of the image lies within a pre-assigned upper threshold and lower threshold.

2. The method as claimed in Claim 4 wherein

if the fourth signal is greater than the pre-assigned upper threshold, then the gain of the CCD camera is incrementally decreased until the fourth signal is

less than the upper threshold value or until the third signal is at a minimum;

if the third signal is at its minimum and the fourth signal is still greater than the upper threshold, then the lens aperture of the CCD camera is incrementally decreased until the fourth signal is less than the upper threshold or until the third signal is at a minimum;

if the third signal is at its minimum and the fourth signal is still greater than the upper threshold, then the brightness of the light source is incrementally decreased until the fourth signal is less than the upper threshold; or

if the fourth signal is less than the pre-assigned lower threshold, then the gain of the CCD camera is incrementally increased until the fourth signal is greater than the upper threshold or the third signal is at a maximum;

if the third signal is at its maximum and the fourth is still lower than the lower threshold, then the lens aperture of the CCD camera is incrementally increased until the fourth signal is greater than the lower threshold or the second signal is at a maximum;

if the second signal is at its maximum and the fourth signal is still lower than the lower threshold, then the brightness of the light source is incrementally increased until the fourth signal is higher than the lower threshold.

3. The method as claimed in claim 2 wherein said method further includes the steps of recording the image of the breast being examined, together with said first, second and third signals and regenerating the image for comparison with a later generated image.

4. The method as claimed in claim 3 wherein said generating said later generated image comprises the steps of retrieving the recorded first second and third signals, increasing or decreasing the gain of the CCD camera until the third signal equals the recorded third signal, increasing or decreasing the lens aperture of the CCD camera until the second signal equals the recorded second signal, increasing or decreasing the brightness of the light source until the first signal equals the recorded first signal.

5. An apparatus for examining breast tissues and producing a standardized

image of a breast, said apparatus comprising:

a light probe (10) to transilluminate breast tissues being examined with a light;

a CCD camera (12) to collect light transilluminated through the breast tissues;

a computer processing system (38) for transforming the collected light into an image;

a monitor connected to the computer graphical processing system for displaying the image having a mean grey scale.

a first sensor (46) adapted for detecting the brightness of light emitted from the light probe;

a second sensor (28) adapted for gauging the gain of the CCD camera;

a third sensor (48) adapted for detecting the mean grey scale of the image, wherein said computer data processing system (38) monitors said sensors and generates a plurality of control signals responsive to said sensors for regulating the image to a standardized image.

6. The apparatus as claimed in claim 5 wherein said probe comprises

a housing having an illuminating end for abutting against a breast for illuminating breast tissue thereof,

a light source (62) mounted within the housing for generating a light beam, and

a light transmitting rod (52) mounted at the illuminating end of the housing for receiving said light beam and collimating the light beam as it passes therethrough and having a textured output surface (56) for scattering said light beam as said light beam exits said rod,

a cooling fan (66) mounted within the probe for positively circulating cooling air through the housing.

7. An apparatus as claimed in claim 6 wherein apparatus further comprises:

a light regulating system (26) for regulating the brightness of the light

probe in response to the computer data processing system;

a lens regulating system (24) for regulating the lens aperture of the CCD camera in response to the computer data processing system; and

a CCD gain regulating system (22) for regulating the gain of the CCD camera in response to the computer data processing system.

8. The apparatus as claimed in claim 7 wherein said apparatus further comprises

a fifth sensor (42) for measuring the temperature of the probe,

a sixth sensor (44) for measuring the focal length of the CCD camera lens, and

a seventh sensor (46) for measuring the brightness of the surrounding light.

9. The apparatus as claimed in Claim 8 wherein said apparatus further comprises:

a control keyboard (30) for controlling operations during the course of imaging, wherein said control keyboard is connected to the computer data processing system (38) and to the light source probe (10) respectively.

10. An apparatus for examining breast tissues and producing a standardized image of a breast, said apparatus comprising:

a light probe (10) to transilluminate breast tissues being examined with a light, said light probe (10) comprising a housing having an illuminating end for abutting against a breast for illuminating breast tissue thereof, a light source (62) mounted within the housing for generating a light beam, and a light transmitting rod (52) mounted at the illuminating end of the housing for receiving said light beam and having a textured output surface (56) for scattering said light beam as said light beam exits said rod, a cooling fan (66) mounted within the probe for positively circulating cooling air through the housing;

a CCD camera (12) to collect the light transilluminated through the breast tissues;

a computer processing system (38) for transforming the collected light into an image, said computer processing system (38) comprising a graphic storage (32),

a network and a printer;

a monitor connected to the computer graphical processing system for displaying the image having a mean grey scale;

a first sensor (20) adapted for detecting the brightness of light emitted from the light probe;

a second sensor (28) adapted for gauging the gain of the CCD camera;

a third sensor (48) adapted for detecting the mean grey scale of the image;

a light regulating system (26) for regulating the brightness of the light probe in response to the computer data processing system;

a lens regulating system (24) for regulating the lens aperture of the CCD camera in response to the computer data processing system;

a CCD gain regulating system (22) for regulating the gain of the CCD camera in response to the computer data processing system;

a fifth sensor (42) for measuring the temperature of the probe;

a sixth sensor (44) for measuring the focal length of the CCD camera lens;

a seventh sensor (46) for measuring the brightness of the surrounding light;

a control keyboard (30) for controlling operations during the course of imaging, wherein said control keyboard is connected to the computer data processing system and to the light source probe respectively;

wherein said computer data processing system monitors said sensors and generates a plurality of control signals responsive to said sensors for regulating the image to a standardized image.

11. The apparatus as claimed in Claim 10 wherein said control keyboard has a manual/automatic switch key (74), a key for maintaining images in a "freeze" mode (122), a key for enhancing the brightness of the light source (76), a key for diminishing the brightness of the light source (78), a key for regenerating the imaging parameters (124), and a key for locking the parameters (123).

12. A light probe for use in detecting abnormal changes in breast tissue, said probe comprises

a housing having an illuminating end for abutting against a breast for

illuminating breast tissue thereof,

a light source (62) mounted within the housing for generating a light beam, and

a light transmitting rod (52) mounted at the illuminating end of the housing for receiving said light beam,

a cooling fan (66) mounted within the probe for positively circulating cooling air through the housing,

wherein the improvement is characterized by the rod (52) having a textured output surface (56) for scattering said light beam as said light beam exits said rod for illuminating breast tissue.

13. The light source probe as defined in Claim 12 wherein said output surface (56) is polished to a ground glass texture.

14. The light source probe as defined in Claim 12 wherein said output surface (56) is polished to a lattice feature of at least two rows of regular parallel crisscrossed convexes.

WO 94/24927 PCT/CA93/00441

FIG.1.

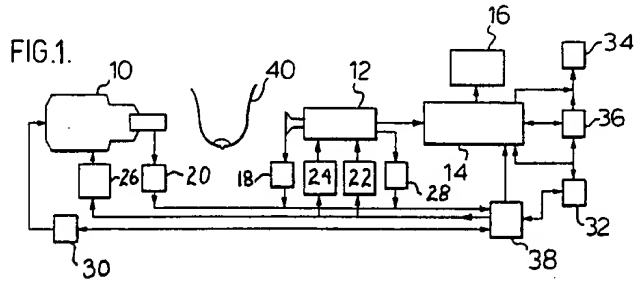


FIG.2.

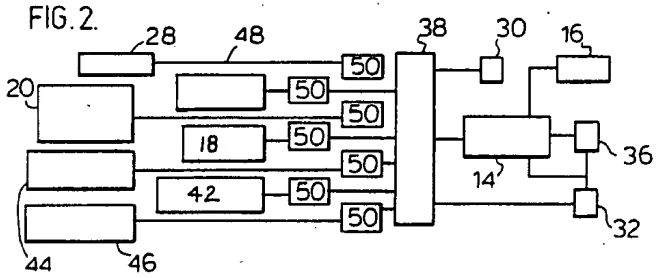


FIG.3.

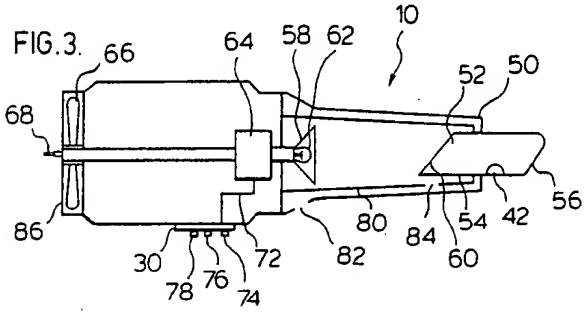


FIG.4.

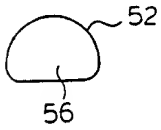


FIG.5.

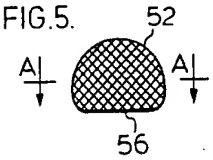


FIG.6.

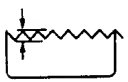


FIG.7.

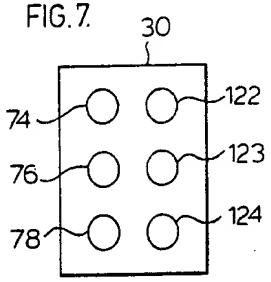


FIG.8.

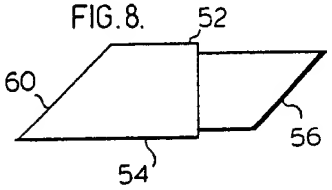


FIG.9.

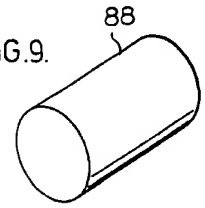


FIG.10.

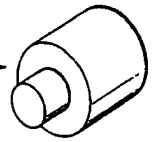


FIG.11.

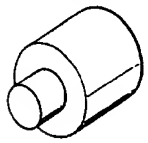


FIG.12.

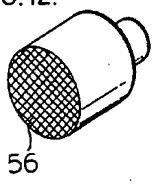


FIG.13.

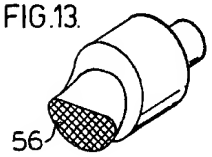


FIG.14.

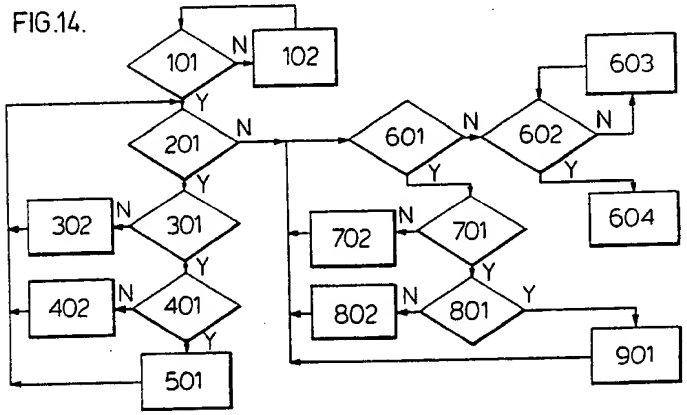
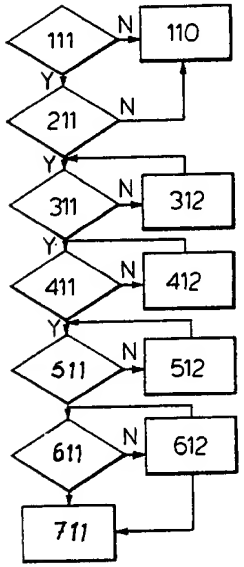


FIG.15.



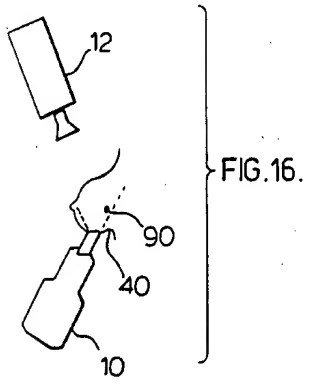


FIG.16.

FIG.17.

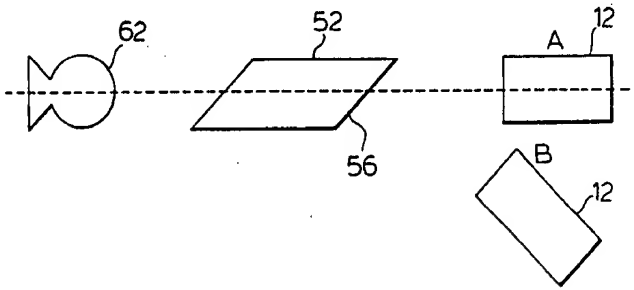


FIG.18.

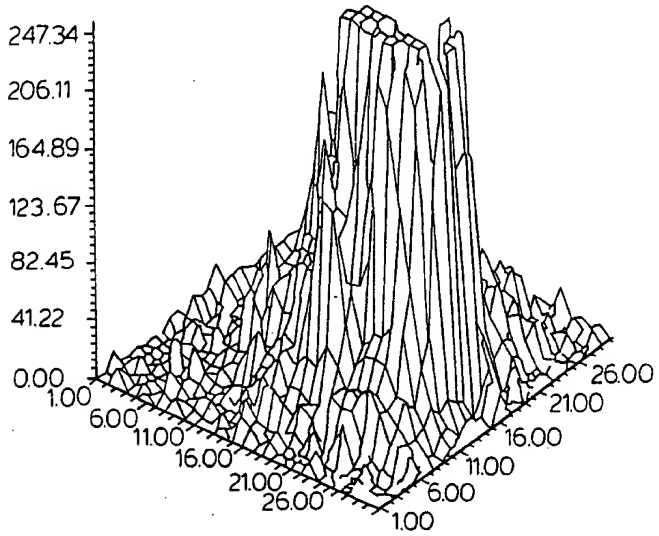


FIG.19.

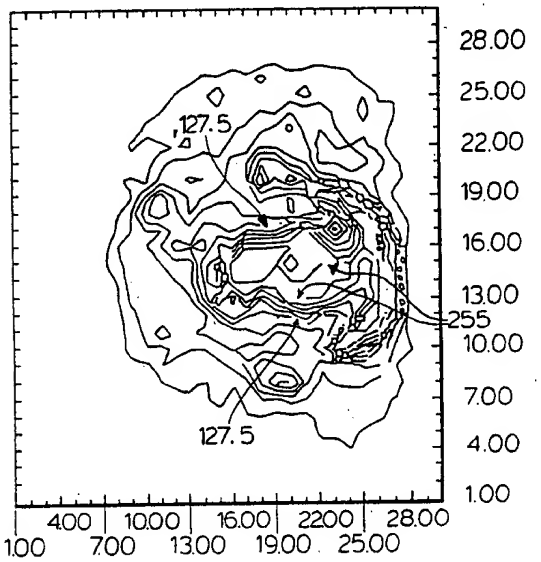


FIG. 20.

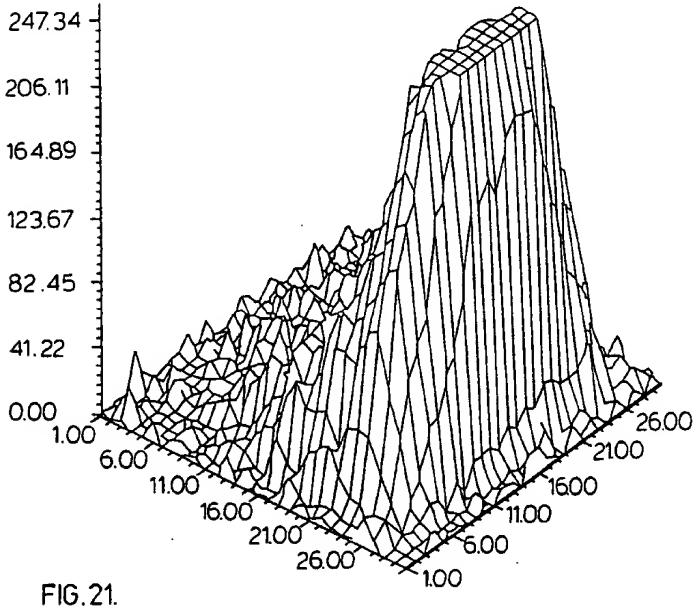


FIG. 21.

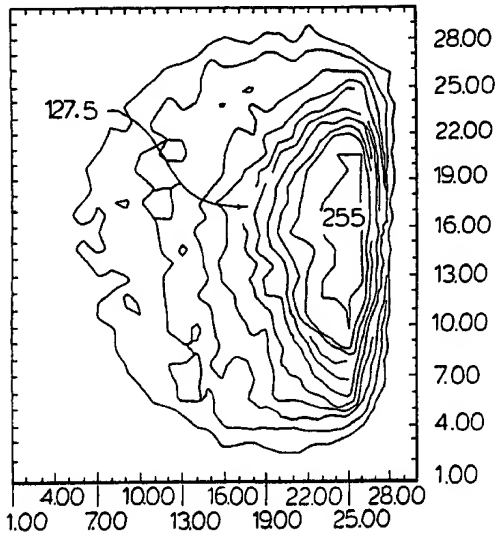


FIG. 22.

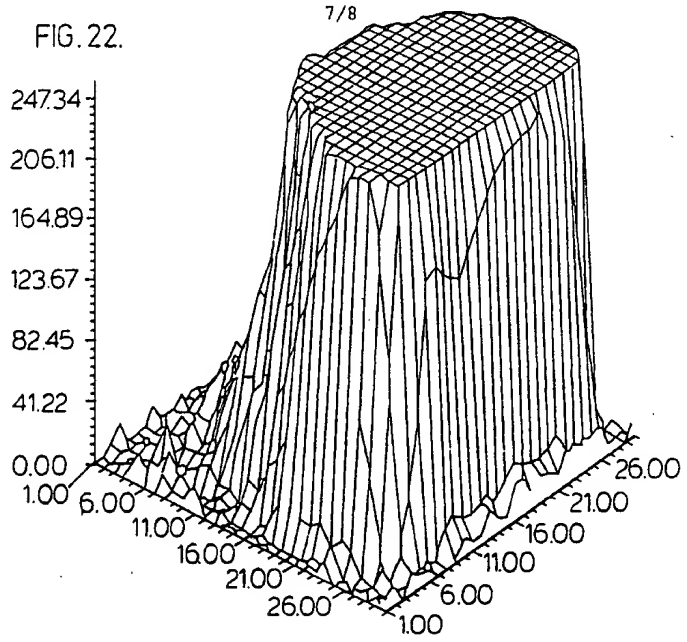


FIG. 23.

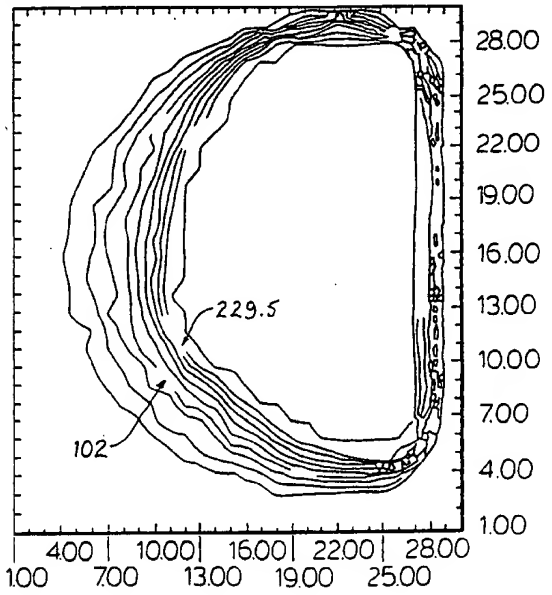


FIG. 24.

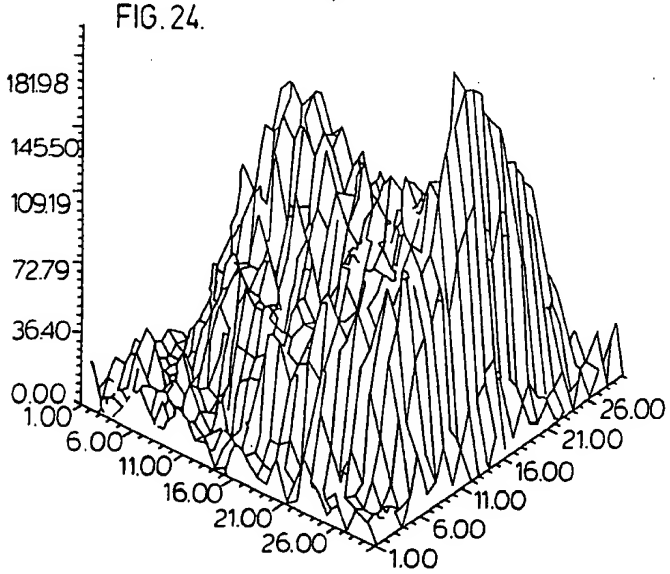
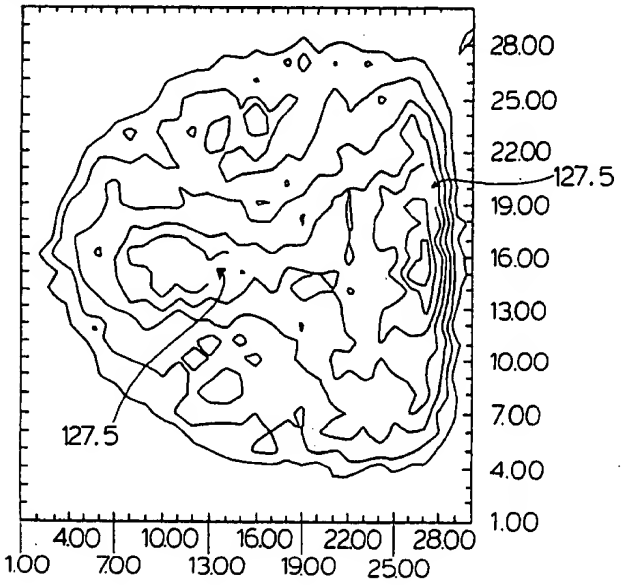


FIG. 25.



INTERNATIONAL SEARCH REPORT

International application No.
PCT/CA 93/00441

A. CLASSIFICATION OF SUBJECT MATTER
IPC 5 A61B5/00

According to International Patent Classification (IPC) or to both national classification and IPC

B. FIELDS SEARCHED

Minimum documentation searched (classification system followed by classification symbols)
IPC 5 A61B H04N

Documentation searched other than minimum documentation to the extent that such documents are included in the fields searched

Electronic data base consulted during the international search (name of data base and, where practical, search terms used)

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category *	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
A	EP,A,0 447 708 (LONG XING MESD CO. HAI DIEN BEIJING) 25 September 1991 cited in the application see the whole document ---	1,5,10, 12
A	WO,A,88 08272 (THE UNIVERSITY COURT OF THE UNIVERSITY OF ABERDEEN) 3 November 1988 see the whole document ---	1,5,10, 12
A	US,A,4 651 744 (D.L.BRISTOW ET AL.) 24 March 1987 see the whole document ---	1,5,10
A	EP,A,0 140 633 (SOMANETICS CORP.) 8 May 1985 see abstract; figures 1-10 --- -/--	1-3,5, 10,12

[X] Further documents are listed in the continuation of box C.

[X] Patent family members are listed in annex.

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Date of the actual completion of the international search	Date of mailing of the international search report
10 February 1994	25 -02- 1994

Name and mailing address of the ISA	Authorized officer
European Patent Office, P.B. 5818 Patentlaan 2 NL - 2280 HV Rijswijk Tel. (+31-70) 340-2040, Tx. 31 651 epo nl, Fax: (+31-70) 340-3016	Hunt, B

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INTERNATIONAL SEARCH REPORT

International application No.
PCT/CA 93/00441

C(Continuation) DOCUMENTS CONSIDERED TO BE RELEVANT

Category *	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
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A	EP,A,0 529 608 (AIWA CO. LTD.) 3 March 1993 see the whole document	1,5,10

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INTERNATIONAL SEARCH REPORT

information on patent family members

International application No.
PCT/CA 93/00441

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